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Application of Synchronous Compensators in the GB Transmission Network to Address Protection Challenges from Increasing Renewable Generation

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Summary

The GB transmission network is experiencing significant changes in its generation mix, with increasing volume of renewables and the decommissioning of large-scale thermal power plants. One of the main challenges resulting from these changes in the generation portfolio is the potential impact on the reliable operation of the existing protection schemes. Specifically, the likely decrease in the fault level may result in conventional protection schemes being slow/failing in detection faults, and the decrease of the system inertia would lead to a power system being more sensitive to disturbances, which may subsequently lead to undesired operation of Rate of Change of Frequency (RoCoF) – based Loss-of-Main (LOM) relays.

Synchronous compensators are considered to have the potential to offer, among other benefits, a boost to system inertia and an increase of system fault level, which could facilitate the operation of protection systems in future energy scenarios. This paper presents the initial studies conducted under a project that has been initiated by a number of utility companies in the UK, focusing on the demonstration and deployment of the first synchronous compensator at a strategic point in the GB transmission system. The studies investigate the potential impacts of a GB transmission system with high penetration of non-synchronous generation on fault levels and system inertia, while contrasting the results with that of a system reinforced by synchronous compensation.

The results of the inertia studies show that synchronous compensation could be used as a potential solution to limit system RoCoF following a disturbance, thereby reducing the risk of a cascading event as a result of the tripping of RoCoF relays. In the fault level studies, it was observed that while increasing the synchronous compensator rating, fault current and short circuit ratio increased, with a faster rate of increase the closer the synchronous compensator is to the fault. This observation suggests that synchronous compensators can also be used to minimise the risk of commutation failure of HVDC links, with the added likelihood of ensuring that the network protection operates correctly in low fault level scenarios.

Keywords

Synchronous compensator, fault level, RoCoF, power system protection.

1. Introduction

The GB transmission network has seen an increasing volume of renewable generation and this trend is expected to continue in the coming decades [1]. In parallel with the integration of renewables, a number of large-scale thermal power plants have been decommissioned with more such plants expected to be disconnected from the network [2]. These changes in generation portfolio will lead to the decrease in fault level and overall system inertia, which will negatively affect the reliable operation of the existing protection schemes.

Fault level, also referred as short circuit level, is an indication of system strength. According to the study conducted by National Grid [1], minimum fault level in GB transmission network will drop rapidly due to the increase in penetration of non-synchronous generation. In the GB transmission network, differential and distance protection are typically used as the main protection while overcurrent protection is used as the backup protection. Differential protection is configured to be sensitive to detect any minimum fault condition, while remaining secure (i.e. unresponsive) to any differential current resulting from non-fault/external fault conditions. With a significant decrease in fault level, the differential current may be too small for the relay to detect [1]. Furthermore, to maintain high security, the initial current setting for differential protection also needs to be configured larger than differential current in non-fault/external fault scenarios (e.g. resulting from line charging current, CT errors, etc.). With a decreased minimum fault level, it also becomes more challenging to adopt settings that maintaining both high sensitivity and security. For distance protection, according to the study in [1], if the fault level is below a certain threshold, it will put the distance protection at risk of undesirable operation. Research presented in [3] also indicates that, with the increasing penetration of converters, the performance of distance protection can be comprised with slow or failed detection of certain faults. Overcurrent protection, based on comparing the measured current with a pre-set threshold, is considered to be most severely affected by the decrease in fault level [1]. The scheme is considered to be at risk of failing to detect the fault or being too slow in operating. RoCoF relays are used for detecting loss of mains. The decrease of system inertia increases the risk of maloperation of these relays during system disturbances. It has been observed in the GB transmission system that the loss of generations led to the undesirable operation of RoCoF relays, leading to a more severe event as some distributed generation (DG) is disconnected at the time that the system needs more active power to restore frequency [4].

Synchronous Compensators (SCs), also known as synchronous condensers, are inherently unloaded synchronous motors and considered to have the potential to offer, among other benefits, a boost to system inertia and an increase of system fault level, which could facilitate the operation of the protection system in future energy scenarios [5]. This paper presents the studies conducted under a project that has been initiated by a number of utility companies in the UK, focusing on the deployment and demonstration of Synchronous Compensator technology through an innovative arrangement for the first time in the GB transmission system. The studies investigate the potential impacts of a GB transmission system with high penetration of non-synchronous generation on fault levels and system inertia, while contrasting the results with that of a system reinforced by synchronous compensation. The study utilised three system models: an in-house developed single bus model, an in-house 37-node reduced GB model and the National Grid 36-node reduced GB model. The single bus model was used to conduct frequency and RoCoF studies, while the reduced models were both used to investigate fault current levels – two versions of the reduced models from different sources were used for comparison and to increase the confidence of the results.

This paper is structured as follows. Section 2 presents the use of the mathematical methodology and the single bus model to investigate the impact of adding SC to RoCoF and largest loss risk; In Section 3, two versions of reduced GB models are used to perform fault level study under scenarios with and without SC; Section **Error! Reference source not found.** provides conclusions and highlights the future work.

2. RoCoF and Largest Loss Risk Study

The GB transmission network operator, National Grid, has recently published the system operability framework (SOF) 2016 [1]. This document highlights, among other factors, the limits to largest loss of demand or generation, which are constrained by the system inertia and RoCoF limit. There is at least 6 GW of distributed generation using relays that could activate if RoCoF exceeds 0.125 Hz/s, putting system security at risk. This places the current practical RoCoF limit at 0.125 Hz/s, leading to the need to manage RoCoF within this limit by constraining the largest single loss when system inertia is sufficiently low. Given the RoCoF limit and system inertia, the largest loss risk (also referred to as loss of in-feed (LOIF) tolerance) can be calculated using the swing equation. The swing equation is stated in Equation 1 below, where dP is the largest loss risk, H_{sys} is the system inertia, f_o is the system frequency, and df is the change in frequency over time, dt, and $\left(\frac{df}{dt}\right)$ is RoCoF.

$$dP = \left(\frac{2 \times H_{sys}}{f_o}\right) \times \left(\frac{df}{dt}\right) \tag{1}$$

Without considering the impact of dynamic system elements (e.g. governors, load response, etc.) the impact of deploying additional synchronous compensation (SC) in a power system can be observed using the swing equation. Fig. 1 below compares a scenario with and without the deployment of 5 GVA of SC with an inertia constant of 2 s; 75 GVAs of system inertia was assumed, representing a low inertia scenario, and a largest loss risk of 375 MW is calculated for a RoCoF limit of 0.125 Hz/s. The mathematical assessment suggests that 5 GVA of SC, can reduce RoCoF from 0.125 Hz/s to 0.11 Hz/s or increase the LOIF tolerance from 375 MW to 425 MW with RoCoF at 0.125 Hz/s.

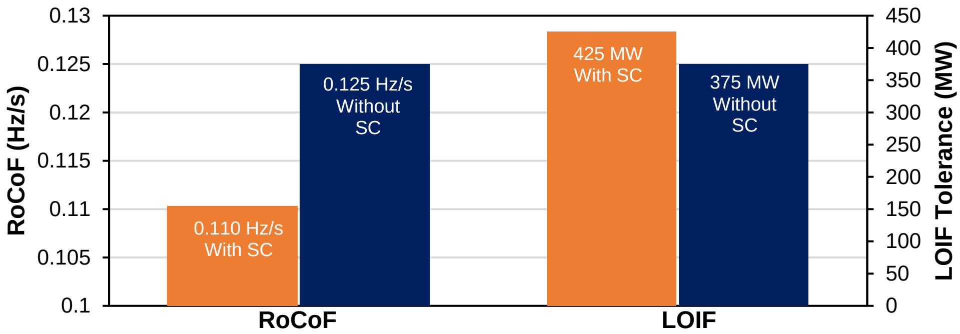

Fig. 1: Loss of in-feed (LOIF) tolerance and RoCoF comparison.

This theoretical analysis of the impact of adding SC is supplemented by a model-based quantification, which use a single-bus representative GB transmission network model (SBM) that includes dynamic system elements, as shown in Fig. 2. The SBM, along with the associated assumptions made, was developed at the University of Strathclyde, with reference to [1], existing literature [6-13], and discussions with industry experts. It can represent the dynamic response of system elements to frequency deviations, with a focus on frequency containment.

The SBM is made up of components of the power system that have been aggregated per their response to frequency events to form individual model elements. The elements of the SBM include: the non-responsive synchronous generator (NRSG), which is made up of synchronous generation that only responds to frequency events via inertia; the responsive synchronous generator (RSG), which is made up of synchronous generation elements that provide both inertia and traditional primary frequency response (TFR) within 10 s following the frequency event; the non-synchronous response (NSR) that encompasses active power responses from non-synchronous sources and can be provided as either TFR or rapid frequency response (RFR) within 5 s following a frequency event; the enhanced frequency response (EFR) element that represents the provision of EFR as full delivery of primary frequency response in 1 s or less [14]; the lost generation simulated that is represented by a separate element called Tripped; the NSG, which comprises all non-synchronous generation that do not provide response to frequency deviations; the low frequency (LF) trip of static non-dynamic response that is represented by the LF Trip element, but not utilized in this paper, since the focus is on dynamic response; the frequency responsive (FR) load, which is comprised of all transmission load components that provide active power response; and all transmission demand inertial response is represented by the inertial (H) load. Any additional synchronous compensation is represented by the synchronous compensator (SC) model element. In this paper, the RSG and NSR elements are assumed to be 75% loaded, with frequency response provided by the 50% of the headroom. A machine power factor of 0.8 is assumed for generation; and secondary response is only considered in terms of additional system inertia, and not as a modelled active power output during frequency containment.

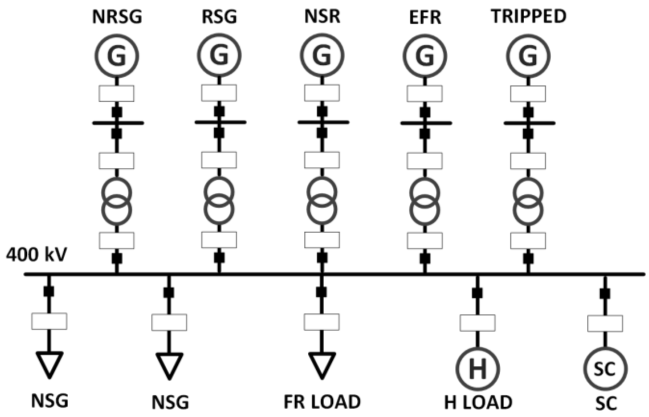

Fig. 2: Single-bus GB transmission network model.

Fig. 3 below illustrates the impact of additional SC, where a comparison is made in terms of RoCoF for scenarios with and without additional SC. This study indicates that 5 GVA of SC, while considering dynamic system elements, can reduce the RoCoF from 0.116 Hz/s to 0.103 Hz/s for a 375 MW LOIF. Similarly, it was also observed that the deployment of 5 GVA of SC for a RoCoF of 0.125 Hz/s raised the LOIF tolerance to 460 MW from 410 MW without SC.

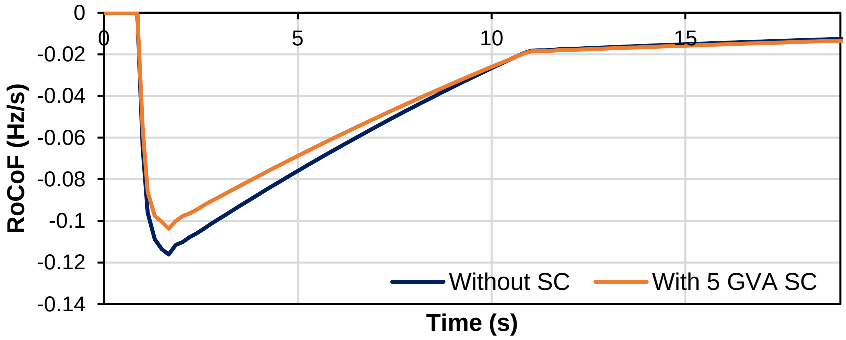

Fig. 3: RoCoF Comparison with system dynamics.

By considering the results of both methodologies, it is observed that the deployment of 5 GVA of SC can be used to allow for a larger loss limit for a given RoCoF limit, minimising the need for system constraints that may be required to secure the system and potentially reducing the costs associated with provision of system security. A system condition that would have originally been at the cusp of breaching the RoCoF limit is brought further within acceptable limits when 5 GVA of SC is introduced to the network. This reduction in RoCoF, following a frequency event, allows more time for other services to respond and could contribute to a reduction in the overall active power requirement for frequency containment. Furthermore, a reduction in the RoCoF can mitigate the risk of a cascading event because of the tripping of RoCoF protection applied to distributed generation, which would exacerbate the initial system disturbance.

3. Fault level study

In addition to the single-bus model-based studies, a 37-node simplified representation of the GB system (depicted in Fig. 4A), developed at the University of Strathclyde [12, 13], was used to conduct fault level and Short Circuit Ratio (SCR) studies to quantify any increase in fault level that may be provided by synchronous compensators under a variety of scenarios. Each node of the 37-node simplified representation of the GB system has terminals for the connection of generators, and has lumped demands within the model to approximate losses associated with parts of the transmission network not explicitly represented. While still subject to minor ongoing developments, it can execute both static and dynamic studies for a range of scenarios. National Grid, the system operator, released a reduced model, depicted in Fig. 4B, for academic studies. Both reduced models were used to compare results and improve confidence in results.

Of particular interest is the potential to avoid/mitigate the risk of loss of commutation on current-sourced converter-based HVDC links, e.g. the Western Link project connecting Ayrshire in Scotland to the Wirral in England [15]. This risk is assessed using the short circuit ratio on the AC system at the terminal(s) of the HVDC link. SCRs of less than or equal to 3 are deemed to increase the risk of loss of commutation (in the event of an AC system fault near a converter's terminals) in LCC-HVDC systems, with a SCR of greater than 3 desired in order to minimise the risk of commutation loss [6].

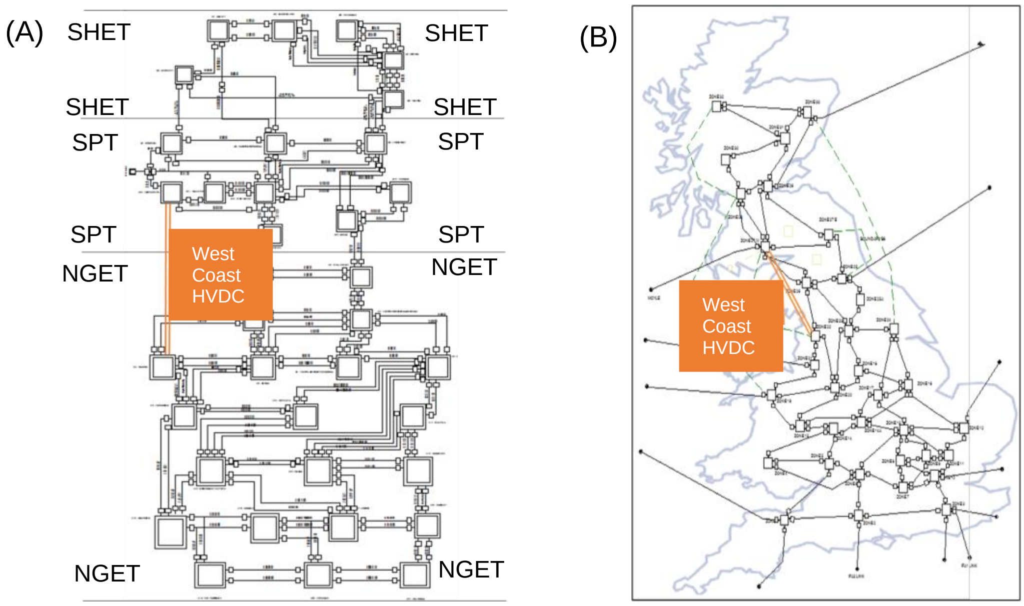

Fig. 4: Reduced network models: A – University of Strathclyde Reduced GB Model; B – National Grid Reduced GB Model.

The impact of synchronous compensation on fault levels at Hunterston was investigated using the reduced GB models depicted in Fig. 4. The computed fault levels were also used to calculate the SCR, and consequently to establish the risk of loss of commutation of the west coast HVDC link during short circuits close to the northern terminal. The study was conducted based on a three-phase busbar fault at Hunterston, under current summer minimum demand conditions using DigSILENT's IEC 60909 [14] minimum short circuit tool on PowerFactory.

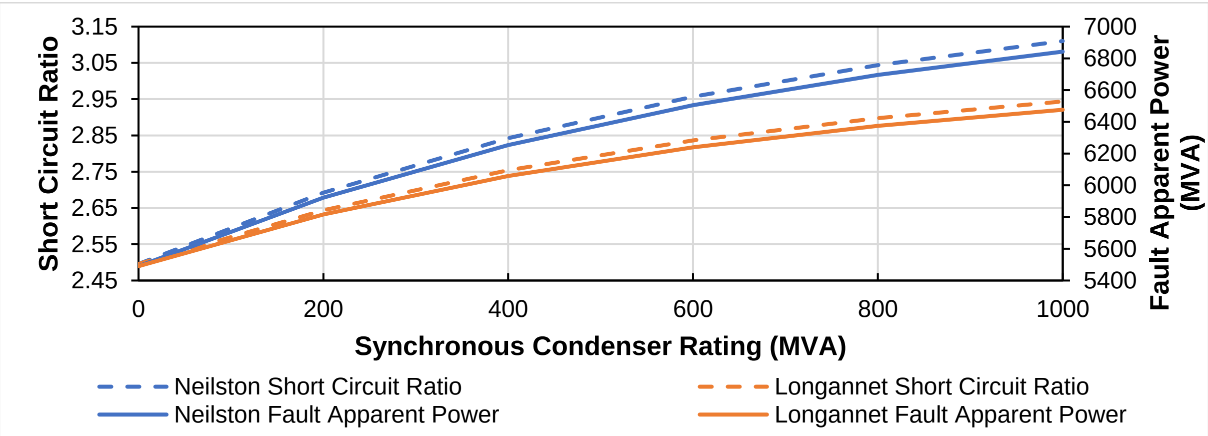

Fig. 5: Fault MVA and Short circuit ratio at Hunterston for increasing penetration of synchronous compensation at Neilston and Longannet.

SC, with capacity varied from 0 to 1 GVA in 200 MVA steps, was placed at two locations, Neilston and Longannet. Fig. 5 shows the trends of the impact on fault levels, in terms of apparent power (at 80 ms after the fault inception) and short circuit ratio at Hunterston with increasing capacities of synchronous compensation at both locations.

The study indicates that the fault level and the short circuit ratio at Hunterston rises with increasing capacities of synchronous compensation, effectively strengthening the AC system. Furthermore, the increase in fault levels and short circuit ratio is pronounced if the synchronous compensator is placed electrically closer to Hunterston.

4. Conclusions

This paper has presented the studies that investigate the potential benefits of synchronous compensation on various aspects of system performance, with a focus on the contribution to fault level and system inertia. The studies show that the addition of synchronous compensation raises the LOIF tolerance for a given RoCoF limit, which in turn reduces the need to curtail generation or apply other system constraints. This would also contribute to the reduction of the risk of cascading DG trips and potential blackouts, due to RoCoF relays tripping when RoCoF limits are breached. It was also observed that synchronous compensation is capable of increasing fault levels in the network, which has the benefit of ensuring that network protection operates correctly in low fault level scenarios and minimising the risk of commutation failure of the West Coast HVDC link during short circuits close to the northern terminal.

Future work will focus on the development of a more detailed synchronous compensator model and its control algorithm for integration to the various network models, as presented in this paper, for further study of its benefits. The investigation of the most appropriate location for the deployment of a synchronous compensator will also be conducted.

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